Studying ultrafast dynamics of element-dependent magnetization dynamics in ferromagnetic Co/Pt multilayer thin films using femtosecond X-ray magneto-optical Kerr effect measurement

The increase in the amount of information that humans deal with has enhanced the importance of the development of high-density recording media. There are various recording methods using semiconductors and dielectrics, but recording media using magnetic materials are widely used because they are nonvolatile and economical. Materials with high magnetic anisotropy are important and are being developed for application to high-density recording media. On the other hand, the method of controlling the magnetization for writing information on such materials is equally important. Currently, heat-assisted magnetic recording (HAMR) and microwave assisted magnetic recording (MAMR), which facilitate magnetization reversal by the external magnetic field assisted by heat or microwaves, are becoming commercially available.

In recent years, optically induced spin dynamics of magnetic materials has been studied and novel phenomena, such as ultrafast demagnetization and magnetization reversal without an external magnetic field, were reported. All-optical switching (AOS) of magnetization has been reported in the ferrimagnetic materials such as GdFeCo and ferromagnetic materials such as FePt and CoPt. In particular, ferromagnetic FePt and CoPt thin films have high magnetic anisotropy and are expected to be used for high-density recording media. These phenomena are realized in an energy-efficient and ultrafast process, and are expected to be applied to recording media.

In the ferrimagnetic material GdFeCo, which is representative of materials showing AOS, the photoinduced magnetic dynamics was investigated by time-resolved X-ray magnetic circular dichroism (XMCD) [1]. It was found that the two magnetic moments of Gd and Fe change with different time constants, resulting in a transient ferromagnetic state via which a magnetic reversal is realized. On the other hand, there is a limited number of element-resolved observations of light-induced transient states in ferromagnetic 3*d*-5*d* alloys such as FePt and CoPt.

Time-resolved XMCD measurements have been performed on FePt at the Pt *L*-edge of the hard X-ray region at SACLA **BL3** [2]. The time scale of the photoinduced demagnetization of Pt was reported to be about 600 fs. However, since the absorption edge of the 3*d* element which gives a large magnetic signal does not exist in the hard X-ray region, measurements investigating 3*d* and 5*d* elements simultaneously have not been performed.

We have performed time-resolved measurements of the X-ray magneto-optical Kerr effect (XMOKE) on ferromagnetic Pt(1.7 nm)/[Co(0.4 nm)/Pt(0.7 nm)]$_3$/Co(0.4 nm) multilayers using SACLA **BL1**, which supplies X-rays in the VUV region [3]. Elementally resolved observations were carried out using X-rays of the Co M and Pt N edges. The schematic diagram of the experimental setup is shown in Fig. 1. Horizontally polarized X-ray pulses were incident on the sample along the same axis as the excitation laser. The reflected X-rays were measured using the rotational ellipsometry analyzer to determine the rotation of the polarization plane. The photoinduced dynamics were captured by the pump-probe method. With the use of a timing monitor to correct the jitter of the X-ray pulses, the time resolution reaches to ~50 fs [4].

Figure 2 shows the results of the static measurement of XMOKE. The reflectivity of multilayer mirror of the rotational ellipsometry analyzer depends on the relationship between the scattering plane and polarization of X-rays. Reflectivity curves are plotted as a function of the angle of ellipsometry analyzer. Those curves are shifted by the change in the direction of the magnetization field as a result of XMOKE. The Kerr rotation angle is obtained as the shift induced by the magnetic field. The Kerr rotation angles are 3 degrees at the Co *M*-edge and 1.5 degrees at the Pt *N*-edge.

Figure 3 shows the results of the time-resolved XMOKE measurements. The vertical axis is normalized by the Kerr rotation angle before laser irradiation. The demagnetization time scales for Co and Pt were evaluated by fitting exponential functions and determined as τ_{Co} = 80 ± 60 fs and τ_{Pt} = 640 ± 140 fs.

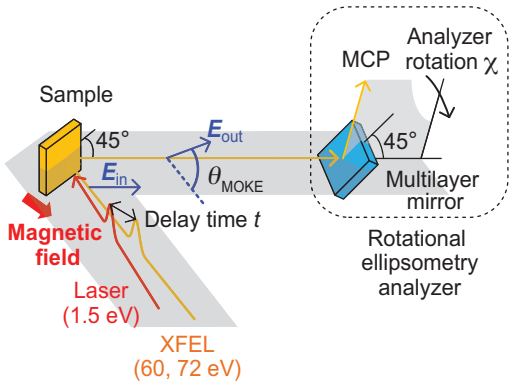

Fig. 1. Experimental setup for time-resolved XMOKE used in SACLA BL1.

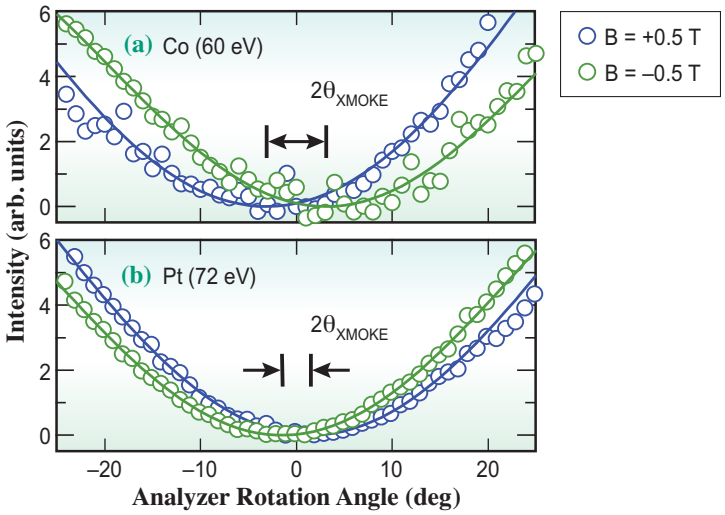

Fig. 2. Reflectivity intensities plotted as a function of polarization analyzer angle for Co M (60 eV) **(a)** and Pt N (72 eV) **(b)** edges.

We proposed an explanation for this difference on the basis of the electron transfer between Co and Pt layers described in our paper [3].

The results of our study show that there is a clear difference in demagnetization time for both Co/Pt superlattices, with the demagnetization time for the 3*d* elements Fe and Co being less than about 100 fs, and the demagnetization time for the 5*d* element Pt being about 600 fs. This is similar to the results of the time-resolved XMCD of GdFeCo, where the demagnetization time of Fe is about 100 fs and that of Gd, a 4*f* element, is about 400 fs. Thus, we suggest that we have obtained an important guiding principle that, for ultrafast spin manipulation such as laser-induced magnetization reversal, it may be important to combine two or more magnetic elements with different photoinduced magnetization time scales. We obtained, for the first time, element-dependent spin dynamics using time-resolved XMOKE in VUV XFEL. This approach will be useful for studying the ultrafast magnetization dynamics of advanced magnetic materials.

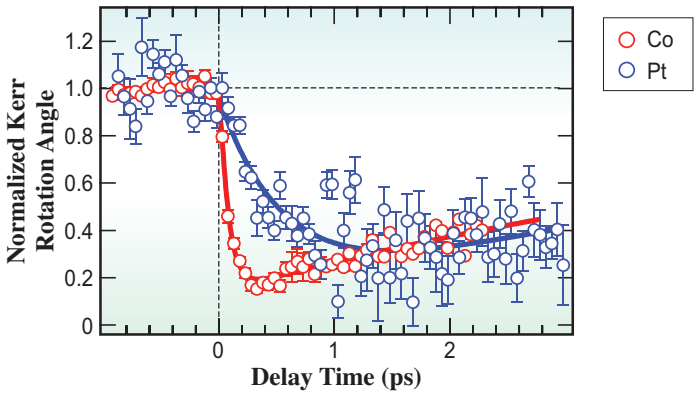

Fig. 3. Kerr rotation angles of Co and Pt edges. Kerr rotation angle is normalized to the initial value before photoexcitation. Solid lines indicate the results of fitting.

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